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J. F. Campbell.

NOTES ON GLACIERS.

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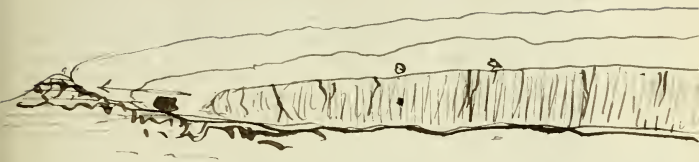
This does not seem to bear upon the action of glaciers of large size, over deep places. So is like drawing conclusions as to rivers inferred from the action of a burn on sea sand where the water is spread during dry weather. Because he finds a big stone past over which ice has flowed at the end of the glacier he seems to argue that heavier

ice did not push the stone to its present place.

If a glacier can dig a small basin a tarn or such like as this author says.

I say that a bigger glacier could dig a bigger & deeper hollow in more time, & may have hollowed out the basins which now hold alpine lakes like Como &c. I believe that most of the alpine glens were chiefly hollowed out by glaciers. If rivers dig beds, and this cannot be denied, then glaciers flowing like slow rivers must also dig beds of larger size. So have I said to Judd here at Kidday Lodge.

[*Extracted from the* Geological Magazine, Decade II., Vol. III. No. 5, May, 1876.]



SOME NOTES ON GLACIERS.

By the Rev. T. G. Bonney, M.A., F.G.S.

As missiles are falling thick like hail upon Mr. Judd since his challenge to the Glacialists, I take the opportunity of putting together a few notes, made during an Alpine journey last summer, which would have been published sooner, had more time been at my disposal. The lower parts of the Gorner, Arolla, Des Bossons, Des Bois, and Argentière Glaciers were carefully studied, but others received passing attention.

1. *Ground Moraine.* — The Glaciers of the Swiss and Savoy Alps have been retreating for several years; hence if anything like ground moraine existed, this would be a very favourable time for observing it. In no case have I been able to find signs of any deposit resembling Till or Boulder-clay; the detrital matter which is scattered, generally sparsely, over the slope left bare by the retreating glacier, has fallen from its surface, like ordinary terminal moraine. Further, by availing myself of crevasses, etc., I have made my way occasionally for some little distance beneath the ice. Nothing has been seen but bare rock, with now and then a film of mud or a passing stone. In short, the result of an experience of some years has convinced me, that if anything like the Till or Ground Moraine of recent glacialists exists in the Alps, it is a very local and exceptional phenomenon. It had sometimes occurred to me, as I believe it has to others, that much till-like matter might be produced from a residuum of stones and mud which had been once involved in the ice of the glacier. My more careful observations during the present year have shown me that these cases of included materials are more exceptional and less abundant than I had anticipated.

2. *The Erosive Power of Glaciers.*—As I have already several times stated, it seems to me very difficult to reconcile the great erosive power attributed to glaciers with a great till-productive power, when overriding their terminal moraines and the rubbish in the lower valley. Some facts which I noticed last summer appeared to have an important bearing on this question. At the present time, the end of the Glacier des Bois just reaches the level bed of the Arve valley, and reclines on ice-worn rocks, with its extremity fitted into a sort of glen or ravine, not more than about thirty yards

across. Below it there is a stony plain covered with the usual mixture of rounded and angular blocks—mica-schist, gneiss, protogine, etc. Among these, a short distance from the end of the glacier and rather near the left bank of the valley, is a huge block of protogine about 12×8 yards area and 4 high. The top of this, and to some extent the sides also, are striated by ice moving in the direction of the present glacier. The Glacier of Argentière is in a nearly similar position; about the last fifty yards rests on the stony bed of the Arve valley, the remainder lies on rocky slopes. In front of it there is an extensive area, now covered with boulders, which, within the last few years, has been abandoned by the ice, and is inclosed by a comparatively fresh terminal moraine. Many of the smaller blocks on this area, now almost concealed by rubbish scattered from the retreating glacier, are smoothed and striated as if by passing ice, but the general uniformity, however, of their upper surface is unfavourable to the idea of the glacier having any great power of "churning up" the deposit beneath. Here and there are large prominent protogine blocks, several of which distinctly show by the striations on their sides and surface, that the glacier has flowed over them. Three lie near together; their tops are polished and striated, and littered over with moraine; they do not form part of a lateral or ordinary terminal moraine, but are in an open plain. Striations, *stoss* and *lee seite*—everything is just as it should be had the glacier flowed over them, and each has a "tail" of moraine. The largest was about 12×7×5 yards.

To return to the glacier itself. Where the ice rests on the level stony plain, the subjacent materials, so far as I could make out, are little if at all disturbed. This fully agrees with everything that I have ever observed, viz. that when the glacier is passing over level or slightly inclined materials, it does not much disturb them, but thrusts up in front, when advancing, at most a mere scarf skin of turf or debris. I questioned my guides, Franz Bürgener and Jean Martin, both men of experience and more than ordinary intelligence. They gave it as their belief, that when a glacier descends a slope of moderate inclination, there is only bare rock beneath; when it passes over a tolerably level surface, it overrides the debris in front, without much disturbing it.

The slope of rock, a considerable portion of which has now been exposed by the shrinking of the glacier, lies at an angle of about 15° or 20°. On ascending that on the left bank for some little distance, I found it possible to pass between the ice and the rock, and availed myself of the opportunity, making sketches of the largest grotto. I copy the following from my note-book as the result of my observations: (*a*). The ice, when in contact with the rock, was remarkably clean (as was the rock), and but few stones were frozen into it. The glacier adapted itself very remarkably to the inequalities of the rock (a gneiss, not protogine), actually fitting itself into hollows some 2 feet deep by 3 or 4 wide. (*b*). The ice, though thus filling up the larger inequalities, does not quite fit into the smaller. The unworn space at the base of a *lee seite* cliff depends on

decreasing
If a stone has been pushed by ice till the force is expended the ice will flow past the stone.
So it is in a river in flood.

several things, but speaking generally it rarely exceeds the height of that cliff, and is narrower on steep than on gentle slopes. (*c*). The ice appears to enter these cavities, not by fracture and regelation, but by change of form, as in the case of a plastic body, for it is remarkably clear and solid-looking. (*d*). Looking into the exquisitely blue mass of the glacier, I saw here and there a little pocket of mud imbedded, and a few stones; but I think 27 cubic inches of rock to a cubic yard of ice would be much above the average proportion. (*e*). There were no signs whatever of the glacier being able to break off or root up blocks of the subjacent schistose rock; it seemed to simply wear away prominences.

It may be well to warn persons unaccustomed to glaciers that, in examining their flanks and ends, there is often danger from falling ice and stones. In doing the above work, I always acted under the advice of an experienced guide, and know the habits of glaciers pretty well myself; yet, in the afternoon of the day when these observations were made on this Argentière glacier, many tons of ice fell either on or very near to a place where we had been working.

To conclude. The above observations tend to show that ice is a far more plastic substance (be the cause of the plasticity what it may) than some physicists would allow, and this has been confirmed by the remarkable experiments of Herr Pfaff, an account of which (*Nature*, vol. xii. p. 316) was almost the first thing to meet my eye on my return to England. They further indicate that this very plasticity, which in some respects is favourable to, in others militates against, its erosive power; as it occasionally flows, after the manner of water, over and round an obstacle, instead of sweeping it away, and appears to pass over debris, as a river does over a gravelly bed. I am thus confirmed in my view that "Ground Moraines," in the ordinary sense of the word, are very exceptional, and that the explanation commonly given of Till (*e.g.*, Great Ice Age, p. 87) is incorrect. Further, I am confirmed in regarding a glacier as an agent of abrasion rather than of erosion, and though I admit that on the whole it seems sometimes the simpler plan to attribute to the action of glaciers certain tarns and even small lakes, yet when I come to study them in detail I am confronted with so many indications of the inability of glaciers to excavate, except under peculiarly favourable circumstances, that I feel convinced great caution must be exercised in referring to their action a rock basin of even moderate dimensions.

This leaves the question as a measure of Scope. basin an inch deep at one end of a Scale, and the bed of the ocean at the other. This is not much of a proper

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